Tidal Evolution

by
B.R. Baumgardt

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LOS ANGELES

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A Concise Statement of the effect of Tidal Friction on the Diurnal Motion of the Earth.

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Tidal Evolution

By B. R. Baumgardt.

All phenomena may be grouped into two classes—those that are rythmic or periodic in their nature, and those that are constant and unchanging, that is, do not increase and then decrease with a regular rythmic periodicity.

To the first class, which is by far the largest, belong all the more obvious phenomena connected with the various manifestations of force in nature, such as light, heat, electricity, sound, motion, etc., as well as those more mysterious ones which we comprehend under the general term of life.

The swaying motion of a reed in a stream, the rustling of the leaves in a tree, the pulsation of the blood in the arteries and veins of the human body, the rise and fall every twelve hours of the tides on our seashores, the periodic maxima and minima every eleven years of spots on our primary, the sun, the accelerating and retarding motions of the planets in their celestial orbits, the inequalities of our satellite, the precession of the equinoxes—that wonderful wabbling motion of our earth's axis around the celestial pole in a majestic orbit requiring 25,000 years for its accomplishment—the occillating change of position of the major axis of the earth's elliptical orbit—the great cycle of the solar system, when, according to La Grange, all the planetary perturbations shall have compensated each other and a new cycle commenced, the wonderful periodic increase and decrease of light in many of the variable stars and many other astronomical phenomena are all, I think, typical illustrations of the first class, or those that are decidedly rythmic in their nature.

But all phenomena are not of this kind. There are some astronomical phenomena which, at least in their broadest and most philosophical sense, differ entirely from this class. They do not increase and then decrease in regular rythmic variability, and for this reason differ entirely from the more obvious ones such as I have enumerated. To one of these I am about to invite your attention for a while this evening, and I hope to be able to show you that in the subject we are to consider we are really dealing with one of the most important factors in the evolution of our earth-moon system.

All intelligent people who have lived by the seashore are familiar with the rise and fall of the sea which takes place twice in every diurnal rotation of the earth on its axis. Long ages ago these tides ceased to be a mystery to man, and in fact before their theoretical explanation was mathematically explained man was perfectly acquainted with their action, their intensity, their maxima and minima, known as spring and neap, and most important of all, with the wonderful fact that in some mysterious way these tides were connected with the position of the moon in relation to the sun. Both Pliney and Aristotle refer to the alliance between the times of high water and the stage of the moon.

Not however, until Sir Isaac Newton in 1687 presented to the Royal Society his immortal *Principia*, was it possible for men to understand the abstract principle of the cause of the tides. In this celebrated work Newton, in a manner which makes it seem as if he was divinely inspired, unfolded to the astonished world, the mechanical theory of nniversal, gravitation, showing that every particle of matter in the universe attracts every other particle with a force which is ever proportionate to the co-attracting masses, and inversely proportionate to the square of the distances separating them.

The moon, therefore, attracts every particle of matter on our earth, both solid and liquid. The solids, however, are not enabled to yield in such a marked way as the liquids are; for the latter are forced by the moon's attraction to rise bodily toward her to a certain extent, and in this way cause the phenomenon of high tide. It must not be forgotten that the

solid crust is also to a certain degree attracted to the moon, away from the waters on the distant side from the satellite, thus leaving the waters in a high wave behind. This is the explanation of the neap tides. The intervening positions between the two high tides, that is, the positions which are as it were, in quadrature with the moon, form the ebbs.

Thus, with a little reflection, we find that the earth is forced through the attraction of the moon to depart from the spherical form and made as it were to bulge out into an oblate ellipsoid, the major axis of which keeps forever following the direction of the moon in her ceaseless journey around her primary.

But some of you may think that these tides certainly are of a rhythmic character. Do they not rise and fall? Are they not a very pulsation of the ocean, now strong, now weak, but ever changing in a regular periodic succession? And have I not myself just given the rise and fall of the tides as an illustration of rhythmic phenomena?

In answer to this I will simply propose that we change our point of view. No doubt, from a terrestrial and therefore limited standpoint the tides do appear to be of a rythmic character. But let us rise from the terrestrial to the general, to the truly philosophical point of view, rising high enough to view the whole globe at a glance; or let us, perhaps, rather view the axial rotation of our earth from the standpoint of the moon. What now has become of the rise and fall of the tides and their rythmic characteristics? Where now will we detect their periodic spring and neap, their flood and ebb? All have disappeared, being only relative phenomena, caused by our terrestrial surroundings and confined limited point of view. In their place we behold only one single gigantic tidal wave, extending from pole to pole parallel to the earth's axis, forever following in the wake of the moon's course.

What a worthy subject it would be for us this evening to consider some of the extraordinary physical phenomena connected so closely with the action of the tides, such as their surprising smallness in midocean, in the Mediterranean sea,

the Caspian, the Baltic aad other confined areas; their enormous heights, on the other hand, in such places as the English channel and the Bay of Fundy. The high tides of both of the latter places are especiallyinteresting to me, having witnessed them personally from the end of the three-mile pier at Havre on the Channel, and from the wharfs at St. John, N. B., on the Bay of Fundy. Time, however, will not permit of this, and I pass on at once to the consideration of the dynamical question of the friction which the tides are causing on the earth and its effect upon the diurnal motion of the planet.

No truth rests on more firm foundation than the axiom that work cannot be accomplished without the consumption of energy in some of its forms. This is based upon the immutable law of correlation of forces.

Now the tides are performing a wonderful amount of work, rebuilding our continents, hollowing out bays and aiding in the formation of bars, besides raising bodily at the present time, all the waters of the earth on an average three feet every 24 hours. In past ages the force displayed was much greater, depending of course upon the proximity of the moon. Thus, as we shall see a little later, when the moon was only 40,000, instead of as at present 240,000, miles from the earth, the tides, in place of averaging three feet, did indeed average 648 feet in height. Such tides as these would sweep almost every city from the face of the earth. Just reflect upon what an enormous amount of work tides like these must have been able to accomplish, and what important factors they must have been in the evolution of the early stages of the earths' crust.

But from what source is the energy derived at the expense of which all this work was and is today performed?

As the moon is the direct cause of the tides, it would, at a superficial glance appear that we might be justified in attributing the source of energy to our satellite. But is this true? Will it hold good? No doubt it seems plausable, but it is, nevertheless, a fallacy. To illustrate this, permit me to quote an illustration from Sir Robert Ball. He says that it is one of those cases by no means infrequent in dynamics, where the truth is widely different from what seems to be the

case, and illustrates it with the example of a rifle which is fired by the pulling of a trigger by the rifleman's finger. No one would assert that the energy by which the rifle ball was fired off was supplied by the rifleman. Certainly not. The energy was of course due to the gunpowder, and all the rifleman did was to provide the means by which the energy stored up in the gunpowder became liberated.

In almost the same way the tides raised by the moon are simply the originating cause whereby a certain amount of energy stored up in the earth itself is liberated and applied to perform such work as the tides are competent to perform.

The store house of energy upon which the tides through the agency of the moon are making such large and continuous drafts is to be found in the momentum stored up in the axial revolution of the planet. No doubt this is an enormous store house of energy. No doubt it seems to us all but inexhaustible. But as the power drawn from it by the tides *is not replaced*, the irresistible consequence is that the momentum of rotation is being dissipated, and that this rotation is slowly but surely decreasing. As a result the day which is now 24 hours is becoming longer.

If I am not mistaken, it was Immanuel Kant, who, more than a century ago first called attention to the fact that the tides in rolling from east to west were reducing the earth's diurnal motion. He showed that countless æons of time may elapse before the momentum can be completely exhausted, but it is nevertheless true that the energy is decreasing and the relation of the earth-moon system tending toward equillibrium. At present the axial revolution of the earth is not measurably longer than it was 100 years ago. Even in 1000 years the change in the length of the day may perhaps be only a fraction of a second. But the importance attached to this dissipation of momentum lies in the fact that this phenomenon, though acting majestically slow, is not of a rythmic nature but continues right on ceaselessly and eternally in the same direction.

La Place's celebrated theory that opposite currents are as to their effect upon the rotation of the earth as plus and minus

naught, and that there are no forces at work in nature which do not always find their compensating opposites, I believe does not hold good in the case of tidal friction. Silently and slowly though it be, the tides are nevertheless uninterruptedly acting as a brake upon the rotation of the earth, and in millions of years the accumulated effect will not only become appreciable but even of a startling magnitude. Many attempts have been made to compute this increase in the length of the day, but of course the results must be taken with a good deal of reserve. Dr. J. B. Mayer, after an elaborate analysis of the subject, arrives at a value of 1-16 of a second for every 2500 years.

Perhaps the best authority on the matter is Sir William Thomson, who in a careful calculation of the age of the earth's crust shows that it cannot be less than 10,000,000 years, because the figure of our globe differs so little from equilibrium in planetoid compression—that is, the polar compression is nearly the same as that which the present diurnal motion would produce in a molten world. Nearly the same, but not quite. What may be the value of this trifling difference? The product of this discrepancy will furnish us with an approximation of the relative amount of the lengthening of the day. The same high authority has arrived at a valuation of 1 per cent for 20,000,000 years. Out of curiosity I have myself calculated what this 1 per cent means in fractions of diurnal motion, and have found it to roughly correspond to 864 seconds, or 14½ minutes. Therefore, if any assurance can be placed on the figures which Sir William Thomson submits, it would appear that the earth today does require 14½ minutes more to perform one revolution on its axis than it did 20,000,000 years ago. It only needs to be added that this is not presented as an accurate result, but rather as an interesting speculation.

But in accordance with Galileo's third law of motion, that to every action there must always be an equal and opposite reaction, it may be asked in what way this reaction exhibits itself in the tidal action of the earth-moon system. The moon, as we have seen, acts upon the earth by retarding

her axial rotation; the earth conversely reacts upon the moon by pushing her further and further away. In this manner the reaction exhibits itself. At first thought there does not seem to be much importance attached to this phenomenon, but a little reasoning will soon show that in this reaction we are dealing with a problem which for far-reaching conclusions is perhaps unparalled in the whole solar system.

At present the distance separating the two bodies is about 240,000 miles, and the length of the day is about 24 hours. If the theory of tidal friction be true, then both the distance of the moon and the position of the earth must have been shorter yesterday than today, shorter the day before yesterday than yesterday, and so on. Looking backward a million years, the revolution was perhaps only some minutes shorter than it is today, and the radius of the moon's orbit—which of course is the distance of the satellite from the earth—was correspondingly shorter.

Before arriving at the critical result of this analysis, there are two other dynamical elements which must be taken into consideration and thoroughly understood. First, that in accordance with Keppler's second law, that the radius vector always describes equal areas in equal times, it follows that the moon in past ages must have completed her lunation in shorter periodic time than at present. Second, that the quicker the earth turns on her axis the more centrifugal force becomes displayed and that if the rotation becomes too quick the centrifugal force will become so pronounced that it will overcome the cohesion of the particles of the earth and the gravitation which attracts them toward the center. The result would be that the globe would fly to pieces, or, which is still more likely, would leave a ring behind from off its outward bulged equatorial zone.

Thus then by retracing our steps backward in time in accordance with tidal evolution we arrive at a critical time, when the moon must have been grazing the surface of the earth, and when one revolution of the earth on its axis must have corresponded to one lunation of the moon. It would appear that the time required was about three hours.

Prof. G. H. Darwin of Oxford has calculated that this state of affairs of the earth-moon system could not have existed less than 50,000,000 years ago.

Studying the theory of tidal evolution of the past, we therefore find that it insensibly leads us to a belief that the moon was once a part of this earth, and that from a preponderance of the centrifugal force it became in some way or other fractured off and left behind. This, of course, must have taken place when the matter of the system was still in a plastic or molten, or perhaps even in a gaseous state.

But plainly this is onlyan illustration of La Place's celebrated nebular hypothesis—that all the ponderable material now constituting the various bodies of the solar system once have existed as a rarefied mass of gaseous matter—a nebula—and that as this nebula cooled by radiating its heat into space, it contracted and was gradually shaped into its present form.

In the future the moon will continue to retard the earth in her diurnal motion and to increase and separate herself more and more from her primary. In the same way that the earth has caused our satellite to complete one revolution on her axis in the same time as is required for her lunation (thereby forcing her to always exhibit the same face toward the earth), in exactly the same way the moon will compel our earth to slow down the time of the diurnal motion until it corresponds exactly to the moon's periodic time. It has been computed that the length of the month as well as the length of the day at that important epoch will be about 54 of our days or about 1400 hours.

We will then have what is known as a stable dynamical equilibrium, with the earth and the moon always presenting the same faces toward each other, and this state of affairs would last forever, providing that no extraneous forces were brought to bear on the system.

But as every particle of matter attracts every other particle in the universe, it follows that the sun also, must, in the same way as the moon, raise tides on the earth. So the sun does, too, but as the tide generating power of attraction, as far as distance goes, acts on the inverse square, we have so

far not found it necessary to even mention the solar tides. But when the earth-moon system has attained equilibrium the sun-raised tides will continue right on in their action. To be sure, they are very small compared to those raised by the moon, but it is well to remember that it is just these small forces acting day in and day out, silently, quietly, persistently, uninterruptedly in the same direction, which in the end accomplish stupendous results. When the earth and moon shall have come to a mutual rest, the solar tides will continue to retard the earth in her diurnal motion until at last the day will become longer than the month.

This may seem to many to be an impossible state of affairs—that the month which is now 27 times longer than the day should actually become shorter. But why not? If these conditions existed today they would be just as natural to us as our present. In fact, we are able with a great deal of satisfaction to corroborate our reasoning with a remarkable example in our solar system. The planet Mars is but little more than half the size of our earth. We are therefore justified in believing that this brother sphere has passed through his evolution quicker and is further along the road of his destiny than is the case with our earth. With this in mind it is interesting to find that in the case of this planet and his satellite Phobes, the Martian day is actually three times longer than the periodic time of the satellite—a signal prophesy of the future of our own earth-moon system.

For the same reason that we expected Mars to be in advance of our earth in his evolution, we would anticipate Jupiter on the other hand to be far behind. On this giant planet, which is so much larger and so much farther distant from our sun —its center of heat and attraction, we may confidently expect to find conditions prevailing which existed on our earth many millions of years ago. And, indeed, in this we shall not find ourselves to have judged wrong. It does not take very many observations with a powerful telescope to tell that this planet is not solid, but is rather in a plastic, if not even in a molten condition. But most significant of all, his axial revolution is accomplished in about 10 hours—a phenomenon which

indeed corresponds to the letter with what tidal evolution tells us was the past conditions of our own earth.

Then again observe the comprehensive fact that both Mercury and Venus, the two planets nearest to the sun, always, according to the most reliable observations, turn the same face toward the sun. Tidal friction has, as it were, arrested the axial revolutions of both of these planets, and forced them to forever pay obeisance to their primary.

Leaving the solar system and passing outward to the siderial we soon find further corroboration of our theory. We have seen this evening that one of the effects of tidal friction is that the two attracting bodies keep pushing further and further away from each other. In the case of the earth-moon system the pushing is pretty well one-sided on account of the great difference in size of the two bodies. But suppose that both bodies were of about the same mass. What would be the result? This is what the consequence would be. The earth would push the moon and the moon the earth about an equal amount, and this would in its turn give rise to exceedingly elongated elliptical orbits. Now one of the most remarkable facts connected with nearly all the binary systems of double stars far away in the bosom of unmeasurable space is their exceedingly eccentric elliptical orbits, caused undoubtedly by mutual tidal action of the components of the systems. My authority for this statement is Herr T. J. J. Lee of Berlin.

There is another collateral consequence which must follow from a combination of tidal action and gravitation on a primitive plastic planet. During the course of evolution the earth's mass must have suffered a screwing motion so that the polar regions have traveled a little from west to east, relative to the equator. Prof. G. A. Darwin of Oxford thinks that this furnishes a possible explanation of the north and south trend of our great continents.

Tidal evolution has indeed furnished explanations for many important questions about the remote past and dim, distant future of the bodies of our solar system. It has perhaps helped us along one more step in our painstaking search for truth and groping for exact knowledge. This is, however,

all that it has done. The mystery of the great whole and the origin of the universe it leaves as great as ever. Sometimes we feel hopeful that eventually the genius of man will unfold it all. And indeed we have good cause and a perfect right to be proud of what the human intellect has been able to accomplish. But it seems to me that every step ahead only tends to show the greater extent of the unknowable. As Carlyle has so finely said in his Sartor Resartus: "System of Nature! To the wisest man, wide as is his vision, nature remains of quite infinite depth, of quite infinite expansion; and all experience thereof limits itself to some few computed centuries and measured square miles. The course of nature's phases on this, our little fraction of a planet, is partially known to us; but who knows what deeper courses these depend on; what infinitely larger cycles of courses our little epicycle revolves upon. To the little tadpole or minnow every cranny and pebble, and quality and accident of its little native creek may have become familiar, but does the minnow understand the ocean tides and periodic currents, the trade winds or monsoons or the moon's eclipses, by all of which the conditions of its little creek is regulated, and may (*unmiraculously* enough) be quite overset and reversed? Just such a little minnow is man, his creek, this planet; his ocean, the immeasurable all; his monsoons and periodic currents, the mysterious course of nature through æons and æons."